APPENDIX E
POST-FIRE MORTALITY ANALYSIS AND GUIDELINES

Introduction

This report documents the evaluation of post-fire mortality in the conifer species affected by the West Side Reservoir fires. The resulting set of criteria is an aid in predicting which trees may or may not survive the effects of the fire. It relies on information from numerous research publications; guidelines developed for other post fire projects; professional experience and observations by fire and vegetation managers on this forest; integration of the site specific conditions in the West Side Reservoir Fire area; and the purpose and need for the project.

Post fire mortality prediction is more of an educated and informed judgment, than an exact science. As a whole, insufficient data exist to develop truly accurate estimates of post-fire survival for most conifers (FHP 2000, Weatherby *et al*. 2001). Survival of trees on either extreme of the fire injury spectrum – those most severely burned and those with little injury – is obviously easier to predict than those with variable degrees and kinds of fire injury. Though we may not have complete certainty, we can reliably estimate the likelihood of mortality based on parameters that we can measure and observe.

Factors affecting tree survival after fire

Coniferous tree species vary widely in their resistance to fire injury. Factors influencing fire tolerance include:

- Bark thickness and character
- Branching habit as it affects crown openness and height of the lowest branches
- Flammability of the foliage
- Characteristics and protection of the buds
- Depth of rooting system

Though these characteristics affect a tree's resistance to injury, there is no conclusive evidence that the likelihood of mortality differs between trees with the same relative level of injury (Ryan and Reinhardt 1988). Once fire injures a tree, a complex of factors determines whether the tree survives or not. These include the tree's pre-fire physiological condition; the type and extent of injury; time of the fire in relation to growing season; site productivity; weather in the years following the fire; a host of potentially damaging biotic agents such as bark beetles and fungi; and interactions between all of them (FHP 2000, Weatherby *et al.*2001, Scott *et al.*1996, Ryan and Reinhardt 1988). For example, smaller, immature but vigorous trees sometimes have a better chance of surviving a given proportion of crown injury than older, slower-growing trees because of their greater ability to recover (Ryan 1990). Multiple stresses on trees, such as drought, mechanical damage, and insects/pathogens (particularly root disease in DF), reduce the ability of trees to survive fire injury. Some species (particularly Douglas-fir and spruce) are very susceptible to beetle attack after fire, though it is not always clear what the relationship of insects to fire injury really is (Furniss 1965, Ryan & Reinhardt 1988, Amman & Ryan 1991, Scott *et al.*1996, FHP 2000, Weatherby 2001).

Primary variables shown in the research literature to have substantial influence on tree survival following wildfire are crown scorch/kill and bole damage. These readily measurable variables will be the main factors focused on in these guidelines. Damage to root systems of trees (i.e. the coarse and fine "feeder" roots near the surface of the soil) also contributes to tree mortality. However, effects on roots have only been partially studied in the literature, and it is very difficult to directly measure in the field (Scott *et al*.1996). Possible root injury will be considered as one of the influencing factors in these guidelines.

Crown damage/crown kill (the % of live crown killed by the fire):

Crown damage is a key mortality indicator because it is physiologically important, often the most severe form of injury, and it is easy to detect (Ryan 1982, Ryan *et al.*1988). Crown kill is usually apparent by the end of the first growing season after the fire by observing the presence or lack of new growth on the tree. Crown scorch (browned needles) immediately after the fire is not always an accurate predictor of the proportion of crown actually killed because of the tolerance of some species to scorch. For example, ponderosa pine has buds that are large and well protected from heat damage and may survive even if all needles are scorched. Larch has an open, heat-dissipating crown in addition to the ability to grow an entire new complement of foliage every year (if the buds are still alive).

Techniques for determining crown kill include using binoculars to check naked eye impressions; observing on clear days and viewing from the side on which the sun is shining. The lee side of the crown (relative to the direction of the fire run) is usually less damaged.

Percentage of live crown related to total tree height is used some situations for implementation, because it can be very difficult to determine the original live crown length (pers. comm. Kamp, 2002). Volume estimates of live crown are often cited in the research literature, rather than a linear estimate. However, observing and calculating a linear estimate of crown damage is an easier and more accurate measurement for broad scale practical application of these guidelines at the project level. It is similar to volume estimates, and a linear estimate is more conservative than a volume estimate because of the conical shape of a typical tree crown, with the disproportionate share of volume located in the lower portions of the crown. However, the relative loss of photosynthetic production due to crown kill is not a 1:1 ratio to the percentage of crown killed, because of the greater photosynthetic efficiency of the upper portions of the tree crown as compared to the lower crown (Wyant 1981).

In the absence of other injury, low percentages of crown kill (i.e. < 30) are not usually considered serious (Ryan 1982, Ryan et. al 1988). A crown kill greater than 70%, however, usually causes substantial physiological stress and it is likely that the tree will die within five years (Weatherby et. al 2001, Ryan 1982, 1988). Survival rates can vary widely, because many interrelated factors ultimately influence individual tree survival. This includes but is not limited to the degree of other fire injury to the tree; its susceptibility to insect and pathogens; individual tree characteristics such as vigor and size; and various abiotic factors, such as weather and site productivity (Ryan and Reinhardt 1988, Scott et. al 1996).

Bole/root crown damage (the % of the bole/root crown circumference killed by fire):

The primary factors controlling the likelihood of bole injury are the fire's duration and the tree's bark thickness (Ryan 1990). Older trees of thick barked species (Douglas-fir, larch and ponderosa pine) have the greatest resistance and can withstand longer duration and hotter fire intensities. Thin-barked species (spruce, subalpine fir and lodgepole pine) are much more susceptible to cambial damage and mortality with even low intensity fire, where the crown of the tree may have suffered little or no scorch.

Some quantification of the relationship of actual measured cambium injury on tree survival has been documented, but it is limited (Wagener 1961, Ryan *et al*.1988). Computed bark thickness (as related to tree species and diameter) and the degree of char on the bole are more often used as a predictor of tree mortality, because they are more readily observed and measured (Ryan & Reinhardt 1988). As indirect measures of cambial damage, they are more subject to error and thus should be used cautiously. However, they have been successfully used as mortality indicators (Wagener 1961, Peterson 1984, Ryan & Reinhardt 1988, Scott *et al*. 1996, Weatherby *et al.* 2001).

Mortality from bole injury is often not apparent immediately, or even one year after the fire (Weatherby *et al*.2001). Water from the root system may still be transported through xylem tissue up to the foliage, allowing photosynthesis to continue. However, with the dead cambium, phloem carbohydrates cannot be transported from the foliage back down to the roots, and the tree will soon die from lack of nourishment. In addition, it may take several years for thick bark over killed cambium to slough off and underlying damage to be apparent (Ryan 1982). Mortality associated with bole and root damage may result from a combination of factors, including direct fire injury, decay/mechanical weakness, and subsequent insects.

Damage to the cambium of the stem or root crown is directly determined by chopping through the bark and into the cambium at four points (quadrants) around the bole of the tree. Dead cambium is typically dry and discolored or darkened, versus live cambium, which will be moist to the touch and usually a light, milky white or pinkish/tan in color. Resin flow from bark or exposed wood between the bark and cambium can be an indicator as well (Wagener 1961, Ryan 1982). It helps to know that damage is ordinarily heaviest on the lee side of the tree and on the uphill side, and that killed patches of cambium are usually widest just above ground level and taper upward.

Noting the appearance of the blackened, charred bole can provide an indirect measure. Deep damage to the stem is typically characterized by bark that is deeply charred around the base and lower bole (not necessarily to the wood) and by bark that has largely lost its surface characteristics. Additional signs include: loss of bark color within the deep fissures of older trees; portions of the bark burned off; and bole scorch running high in the tree. In addition, the condition of the soil, duff and organic layers, and the large fuels burned, at the base of the tree are good indicators. This indirectly indicates the intensity of the fire that occurred at that spot, and thus the possible damage to roots and root crowns that may have occurred. Chopping through the bark to verify cambium damage is an effective method for calibrating a visual inspection and making field determinations.

Tree species and diameter/bark thickness must be considered along with the visual indicators listed above. For example, thick barked trees can show bark charring but still have live cambium underneath. Thin barked species, such as spruce or subalpine fir, may have dead cambium under relatively lightly charred bark.

Consideration of fire damage to the root crown and visible surface roots is part of this evaluation of cambial damage. Severe root damage from surface fire can occur in Douglas-fir, which often develop large, lateral roots close to and above the soil surface. Though the bark on the bole of Douglas-fir can be quite thick and fire resistant, these lateral roots have thinner bark and are easily damaged, even under a low severity ground fire (Ryan *et al*.1988).

Most research and observations indicate that trees with dead cambium in more than two quadrants (>50% of bole circumference) are poor candidates for survival (Ryan *et al*.1988). In many cases, cambium injury in more than one quadrant (>25% of the bole) was found to substantially lower tree survival. This is a threshold used in several existing mortality guidelines (Wagener 1961, Ryan *et al.*1988, Ryan 1990, Weatherby *et al*.2001, Kootenai NF 1995, Bitterroot NF 2001, Trechsel 2002). As described earlier under crown kill, the interaction of other factors with cambium damage, such as degree of other types of fire damage, susceptibility of the tree to insects or pathogens, tree vigor, etc, exert a substantial influence on the tree's probability of surviving. This is important to remember in the case of Douglas-fir in the West Side Reservoir Post-Fire project. Douglas-fir trees with relatively light bole injuries, especially when associated with crown scorch, are quite attractive to Douglas-fir beetles, especially if beetle populations are abnormally high before the fire (Furniss 1965, Scott *et al*.1996, Rasmussen *et al.*1996, Weatherby *et al*.2001).

Application to the West Side Reservoir Project

This report is intended to provide the guidance and criteria to use for assessing individual tree conditions, estimating what trees would be salvaged and which would be left, and evaluating the post-salvage forest condition, as disclosed in the DEIS. The guidelines outlined in Tables 1 and 2 and in the text that follows take into account the situation specific to the project area and the purpose and need for the proposed action.

The main purpose for the proposed salvage actions of the West Side Reservoir Post-Fire Project are to recover merchantable wood fiber to support local communities and contribute to long term yield of forest products. Important resource objectives that are considered include retaining forest structural elements at desired levels (snags, downed wood, living trees), protecting soil productivity, and providing for the needs of wildlife species that live within, and in some cases benefit from, the fire-changed landscape. The vulnerability of fire-injured Douglas-fir and spruce to bark beetle mortality in the next few years is believed to be high. Douglas-fir trees infested with bark beetle are widespread and the overall population levels of Douglas-fir beetles are elevated within the area. In addition, the fires created suitable habitat for increases in both spruce and Douglas-fir beetle populations inside and outside the fire perimeters (refer to Chapter 3 of the DEIS). This situation has been taken into account in development of the guidelines in this report.

The estimated mortality risk determinations in the tables below use the variables of species, diameter (DBH), live crown ratio and estimated cambium kill based on bole char. As described earlier, exploratory sampling through the bark with an axe of the four quadrants of a tree near ground line is a means of estimating cambial damage. This is time consuming and infeasible to apply across the many acres of potential salvage at the site-specific level. However, exploratory sampling is useful for calibrating between visual indicators and actual cambium damage. External appearance of the bole, root crown and soil surface would be used in most situations to assess potential cambial damage, as described under the section on bole/root crown damage.

It must be remembered that the criteria and predictions in the guidelines are based on probabilities and draw upon the available scientific information, as well as professional experience and judgment in the context of the conditions in the project area. By following these guidelines, some trees may be removed that would otherwise live, and some trees that are left will die.

Table 1: Post-fire mortality risk considering remaining live crown (Step 1)

<table>
<tr><th>Species</th><th>D.B.H.</th><th>Remaining live crown length <= 20%</th><th>Remaining live crown length 20-40%</th><th>Remaining live crown length > 40%</th></tr>
<tr><td>Ponderosa pine</td><td>< 14”
>=14”</td><td>X
X</td><td>Go to Table 2
Go to Table 2</td><td rowspan="4">Go to Table 2</td></tr>
<tr><td>Larch</td><td>< 14”
>=14”</td><td>X
X</td><td>X
Go to Table 2</td></tr>
<tr><td>Douglas-fir</td><td>< 14”
>=14”</td><td>X
X</td><td>X
X</td></tr>
<tr><td>All other species (lodgepole, white pine, subalpine fir, spruce, redcedar, hemlock)</td><td>< 14”
>=14”</td><td>X
X</td><td>X
X</td></tr>
</table>

Table 2: Post-fire mortality risk considering cambium damage (Step 2)

Species	D.B.H.	Bole char > 50% of bole/root crown circumference	Bole char 25-50% of bole/root crown circumference	Bole char <25% of bole/root crown circumference and roots exposed/duff consumed	Bole char <25% of bole/root crown circumference and NO roots exposed
Larch, ponderosa pine	All sizes	X			
Douglas-fir	All sizes	X	X		
lodgepole, white pine, subalpine fir, spruce, redcedar, hemlock	All sizes	X	X	X	

(NOTE: An “X” in the tables above indicate a tree that is estimated to have a high probability of dying and that may be designated for salvage if within a proposed unit)

Treatment prescriptions:

Silvicultural prescriptions were developed for proposed salvage units considering the West Side Reservoir Post-Fire Project purposes and objectives, and knowledge of the site specific and landscape conditions unique to the fire areas. These are described in the DEIS (Chapter 2). Prescriptions specify the retention of trees within all salvage units that are currently live and have a good probability of surviving, and removal of most dead and dying trees (other than those needed to provide snag and downed wood habitat). The guidelines outlined in the Tables 1 and 2 above and in the text of this report will be used to help determine these trees.

The guidelines would not apply to live or dead western larch and Douglas-fir larger than the diameters specified for snag retention in the Deadwood Habitat Prescriptions; they would be left on the site. This requirement to provide important large snag/live tree components in this burned landscape, would result in abundant larger diameter snags in some units, more scattered amounts in others (refer to DEIS Chapters 1 and 2, and Exhibit Rd-8). In addition, all live or dead ponderosa pine and hardwoods of all sizes would be retained within all salvage units in all alternatives. These trees are rare across this landscape.

The salvage harvest is primarily in the areas of moderate to high fire severity, where high tree mortality has occurred. Field reconnaissance and plot data show that the majority of trees that would be salvaged will be clearly dead (at or near 100% crown scorch or all fine branches/needles consumed by fire), with little question whether they meet the criteria for removal or not defined in the tables above. Nearly all trees have multiple fire injuries, with crown scorch associated with bole char and damage to root systems in the shallow rooted species. Mortality of trees may occur directly because of the fire injuries, or due to other related factors, such as bark beetle infestation in Douglas-fir and spruce. As much of the literature confirms, this form of post-fire mortality often has a substantial impact on Douglas-fir and spruce (Furniss 1965, Ryan 1982, Amman & Ryan 1991, Ryan & Amman 1996, Rasmussen *et al.*1996, Scott *et al.*1996, FHP 2000, Weatherby 2001).

Presence of successful bark beetle attacks (beetle boring dust, pitch tubes, galleries, etc) indicates a tree that should be salvaged, whether or not it has evidence of fire damage. This is particularly relevant for Douglas-fir and spruce. Not only are these trees imminently dead (i.e. attacks are found over at least half of the bole circumference), they also will contribute to higher beetle populations in the project area, with resulting mortality to live trees. However, Douglas-fir larger than the diameter specified in the snag retention guidelines would be left (Exhibit Rd-8).

Larch and ponderosa pine are the most fire tolerant species in this area. They have thick, fire resistant bark and are deeper rooted, thus it takes a greater amount of heat to cause damage to the boles, root crowns and root systems. Field observations and exploratory sampling to determine cambium damage suggest that most of the time, if there is adequate live green crown in the trees, the fire was not severe enough to damage the cambium, even if the bole is charred. Criteria for retention of larch and ponderosa pine trees in Tables 1 and 2 are conservative, considering their fire tolerance, their value as snags (and live trees) across this landscape, and their lack of vulnerability to the bark beetles of concern (Douglas-fir and spruce beetles).

Shallow rooted species are particularly susceptible to damage of small feeder roots close to soil surface, and include subalpine fir, spruce, western redcedar, and western hemlock. White pine is moderately susceptible. Douglas-fir with large lateral roots at or above the soil surface is very susceptible to root injury. These factors will be taken into account when utilizing Table 2 above.

An evaluation of the duration and intensity of the fire that occurred at and near the base of the tree will help in estimating degree of root injury (refer to visual indicators described under Bole/Root crown section earlier). Almost all the sites proposed for salvage had not experienced a fire for 200+ years before the West Side Reservoir Fire (DEIS Chapter 3, Fire and Fuels). This allowed substantial accumulations of duff and woody debris on these sites. Field reconnaissance suggests that in areas burned at moderate severity, the duration of fire and heat that resulted in the significant reduction of the duff and surface fuel accumulations has been enough to cause at least some degree of root damage to Douglas-fir and other shallow rooted species. Trees in these areas usually show significant charring of their lower bole/root collars, and usually far greater bole charring and crown scorch. Even in some of the areas burned at low severity, an "underburn" with relatively little crown scorch, trees have often experienced significant charring and injury to the lower bole and probably the root systems of shallow rooted species as well.

Live crown ratio would be a major variable used (Table 1 above) at the implementation phase (the timber sale contract development and implementation). It is the most prominent and common injury. It is easier to detect and interpret. It is usually associated with trees that have extensive bole char as well and tends to correlate with cambium injury, though not under all fire conditions (Furniss 1965). It is a common (if not the most common) indicator used in the literature and in practice to predict mortality and develop mortality guidelines. Many studies also identify crown damage as a primary injury contributing to tree death (Wagener 1961, Peterson 1985, Ryan *et al*. 1988, Stephens and Finney 2001) particularly on the thicker barked trees. In evaluation of this criteria, the live crown portion of the tree should show a relatively low degree of fire damage and a high proportion of green, live foliage to be considered "live".

Bole/root crown char, as an indicator of cambium injury, would also be used as a variable in leave tree/salvage tree selection at implementation. It is particularly applicable for use in the thin barked species (lodgepole pine, subalpine fir, spruce, redcedar, and hemlock). These species are very sensitive to bole heating and even light char usually indicates underlying dead cambium. Degree of bole char indirectly reflects the intensity of the fire and thus can help to assess the degree of root injury that may have occurred in more shallow rooted species, as described above. This is also applicable in evaluation of Douglas-fir, recognizing both its susceptibility to root injuries, the resulting increased stress on the tree, and its associated vulnerability to Douglas-fir beetle attack.

All larch that meet the retention tree guidelines would be marked with paint in units that would be winter logged, to ensure they would be not mistaken for a dead tree because its needles are shed in the fall.

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